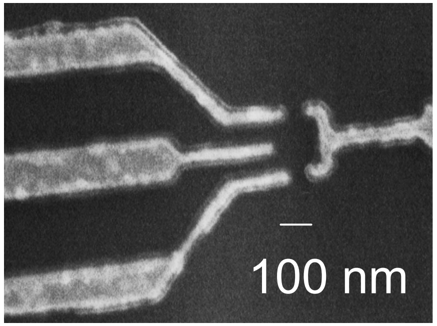
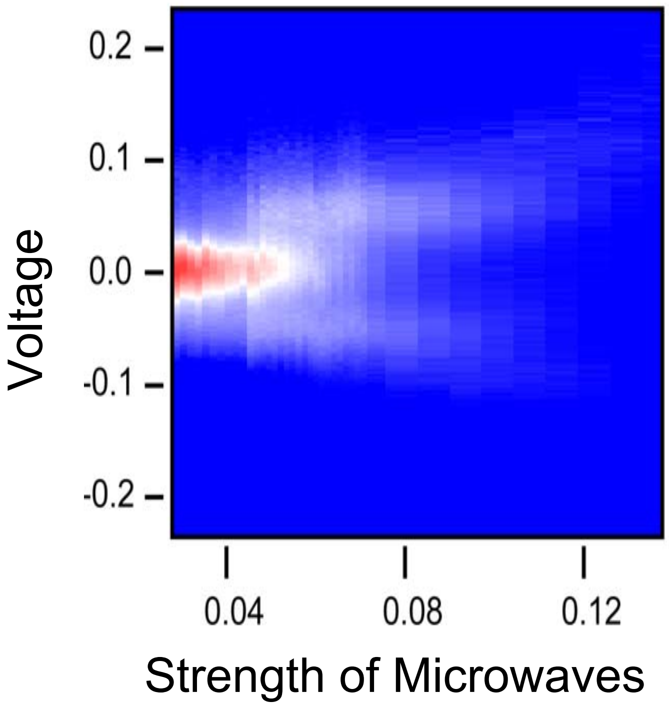
Control of entanglement with Microwaves
M. A. Kastner, MIT, DMR-0102153

The MIT group has studied a Single Electron Transistor (SET) in the presence of microwaves. Voltages on the electrodes shown at the top force the electrons into a small region of space, sometimes called a quantum dot. However, quantum mechanics allows the electrons to be both inside and outside the dot *at the same time*. The bottom figure shows a property of the SET that measures how easily electrons can get through dot, as a function of the voltage pushing them through (vertical scale). Were electrons completely confined to the dot this quantity would be zero. The peak at the left side of the figure indicates that the electrons are both inside and outside, but only when the voltage is very small. As the microwave strength (horizontal scale) is increased the electrons become confined at the small voltages, but are both inside and outside at a larger voltage. This shows that the microwaves change the quantum mechanical state of the electrons. Being simultaneously inside and outside is an amazing aspect of quantum mechanics called "entanglement," whose control is necessary for applications such as quantum computing or cryptography.





The top figure is an electron micrograph of gold electrodes on the surface of a GaAs/AlGaAs heterostructure, which is doped to form a two-dimensional electron gas (2DEG) about 20nm below the surface. Negative voltages on the electrodes remove the 2DEG underneath them, confining the electrons to the region, about 100nm in diameter surrounded by the electrodes. Electrons can move from the top (source) to the bottom (drain) regions of 2DEG only by quantum mechanical tunneling through the potential barriers formed by the two small gaps. We measure the current as a function of source-drain voltage and take its derivative to determine the differential conductance dI/dV, plotted on a color scale in the lower figure. The voltage on the vertical scale is the source-drain voltage. dI/dV measures how easily the electrons can tunnel and is enhanced when the wave-functions inside the dot and in the source and drain are entangled. The peak at zero voltage and zero microwave voltage (horizontal scale in the lower figure) is the signature of the Kondo effect, the strong entanglement of electrons inside and outside the dot. Microwave excitation reduces this central peak and replaces it with two peaks at voltages given by $|eV|=h\nu$, where ν is the microwave frequency. This means that the entanglement is restored, but only for electrons that are excited by $h\nu$. This effect was predicted as early as 1995, but was only observed by the MIT group this year.

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Education:
Kastner's more than 20 graduate students have gone on to careers in research universities, teaching colleges, as well as large and small companies where they are involved in both research and management. Ten percent of his students have been African American and about 30% have been women. He has supervised the introduction of a new studio method of teaching freshman physics at MIT and of a new degree program for students wishing to use physics as a basis for careers in other fields.

Outreach:
Kastner organizes Physics Department lecturers for the MIT summer program for high school teachers. He is on the advisory board of MIT's OpenCourseWare program that makes all MIT courses available to the public.

http://ocw.mit.edu/index.html

The freshman physics courses there have drawn praise from high school students. An interview to help the Boston Museum of Science teach the public about nano-science can be found at http://www.mos.org/cst/article/5651/index.html